AERONOMY AND ASTROPHYSICS

The polar regions have been called Earth's window to outer space. Originally, this term applied to dynamic events like the aurora, staged as incoming solar plasmas encountered the Earth's geomagnetic fields. Unique properties create a virtual screen of the polar upper atmosphere on which the results of such interactions can be viewed (and through which evidence of other processes can pass). During the mid-1980s, Earth's window was extended to refer to the "ozone hole" in the polar atmosphere. As scientists have verified an annual loss of ozone in the polar stratosphere, a window previously thought closed (stratified ozone blocking the Sun's ultraviolet rays) is now known to "open," consequent to chemical cycles in the atmosphere.

A low-frequency receiver listens for electromagnetic activity at a remote Automatic Geophysical Observatory (AGO) site.

NSF photo by Kristan Hutchison

For astronomers and astrophysicists, the South Pole presents unique opportunities. Thanks to a minimum of environmental pollution and anthropogenic noise, the unique pattern of light and darkness, and the properties of the geomagnetic force field, scientists staging their instruments here can probe the structure of the Sun and the Universe with unprecedented precision. Studies supported by the Antarctic Aeronomy and Astrophysics Program explore three areas of research:

- **The stratosphere and the mesosphere:** In these lower regions, current research focuses on stratospheric chemistry and aerosols, particularly those implicated in the ozone cycle.

- **The thermosphere, the ionosphere, and the magnetosphere:** These higher regions derive many characteristics from the interplay between energetically charged particles (ionized plasmas in particular) and geomagnetic/geoelectric fields. The upper atmosphere, particularly the ionosphere, is the ultimate sink of solar wind energy transported into the magnetosphere just above it. This region is energetically dynamic, with resonant wave-particle interactions and joule heating from currents driven by electric fields.

- **The galaxy and the Universe beyond, for astronomical and astrophysical studies:** Many scientific questions extend beyond the magnetosphere, including a particular interest in the Sun and cosmic rays. Astrophysical studies are conducted primarily at Amundsen-Scott South Pole Station or on long-duration balloon flights launched from McMurdo Station. The capability of such balloons is expanding dramatically.

All research projects sponsored by this program benefit from (indeed, most require) the unique physical conditions found only in the high latitudes, yet their ramifications extend far beyond Antarctica. High-latitude astrophysical research contributes to the understanding of Antarctica's role in global environmental change, promotes interdisciplinary study of geosphere/biosphere interactions in the middle and upper atmosphere, and improves understanding of the critical processes of solar energy in these regions. Life exists in a balance on Earth because of numerous chemical and atmospheric phenomena that have developed in the specific atmosphere of this 4.6-billion-year-old spinning planet in orbit 149,637,000 kilometers from a middle-sized, middle-aged star. The 20th-century expansion of traditional astronomy to the science of astrophysics, coupled with the emerging discipline of atmospheric science (see also the Antarctic Ocean and Climate Systems Program), is nowhere better exemplified than in Antarctica.

Background imaging of Cosmic Extragalactic Polarization (BICEP): An experimental probe of inflation.

Andrew Lange, James Bock, and Brian Keating, California Institute of Technology; and William Holzapfel, University of California–Berkeley.

The Cosmic Microwave Background (CMB) provides three strong but circumstantial pieces of evidence that the visible Universe was created by the superluminal inflation of a tiny volume of space: namely,

- the near isotropy (homogeneity) of the horizon,
- the flatness of space, and
- the phase-synchronicity of acoustic oscillations in the early Universe.

To better understand the origins of the Universe, we must probe this epoch of inflation directly. The most promising probe is the unique signature that the gravity wave background (GWB) imprints on the polarization of the CMB. The amplitude of this signature depends on the energy-scale of inflation.

Detection will require only modest angular resolution (about 1 degree), but long integration (about a year) on a restricted and contiguous patch of sky. The 6-month night, the extremely dry and stable weather, and the precise rotation of the sky about the zenith make South Pole Station the ideal terrestrial site for this ambitious project. A CMB polarimeter (BICEP) uniquely capable of detecting the signature of the GWB is being constructed and will be available for deployment in 2003. BICEP will operate simultaneously at 100 and 150 gigahertz (GHz) to both minimize and recognize confusion from polarized astrophysical foregrounds. At these frequencies, a modest (and thus relatively easy to deploy and maintain) 20-cm primary aperture will provide a resolution of 1 degree at 100 GHz and 0.7 of a degree at 150 GHz.

By combining a new polarization-sensitive bolometric detector technology developed for the European Space Agency’s Planck satellite (to be launched in 2007) with four independent levels of signal differencing and a carefully optimized observing strategy, BICEP will reach the current limit on CMB polarization in the first hour of integration, reach the sensitivity of Planck over 1 percent of the sky in the first week, and precisely measure CMB polarization on the critical angular scales of 1 degree to 10 degrees.

Observational cosmology is enjoying a renaissance that has captured the public imagination and serves as one of the most effective vehicles for stimulating interest in science in general. Detecting the signature of the GWB in the CMB would represent a triumph of fundamental physics and cosmology that would revolutionize our understanding of the origins of the Universe. (A–033–S; NSF/OPP 02–30438)

Conjugate studies of ultra-long-frequency (ULF) waves and magnetospheric dynamics using ground-based induction magnetometers at four high-latitude manned sites.

Mark Engebretson, Augsburg College, and Marc R. Lessard, Dartmouth College.

The Earth's magnetic field arises from its mass and motion around the polar axis, but it creates a powerful phenomenon at the edge of space known as the magnetosphere, which has been described as a comet-shaped cavity or bubble around the Earth, carved in the solar wind. When that supersonic flow of plasma emanating from the Sun encounters the magnetosphere, the result is a long cylindrical cavity, flowing on the lee side of the Earth, fronted by the blunt nose of the planet itself. With the solar wind coming at supersonic speed, this collision produces a “bow shock” several Earth radii in front of the magnetosphere proper.

One result of this process is fluctuations in the Earth's magnetic field, called micropulsations, which can be measured on time scales between 0.1 second and 1,000 seconds. It is known that magnetic variations can significantly affect power grids and pipelines. We plan to use magnetometers (distributed at high latitudes in both the antarctic and arctic regions) to learn more about how variations in the solar wind can affect the Earth and manmade systems.

We will study these solar-wind-driven variations and patterns at a variety of locations and over periods up to a complete solar cycle. Since satellite systems are now continuously observing solar activity and also monitoring the solar wind, it is becoming feasible to develop models to predict the disruptions caused by such magnetic anomalies. And while our work is geared specifically toward a better understanding of the world and the behavior of its manmade systems, it will also involve space weather prediction. (A–102–M/S; NSF/OPP 02–33169)

A search for extrasolar planets from the South Pole.

Douglas Caldwell, SETI Institute.

We will operate a small optical telescope at the South Pole to search for and characterize extrasolar planets by continuously following a southern galactic star field with a charge-coupled device photometer and searching for the periodic dimming that occurs as a planet transits its parent star.

The recent discovery of many close-in giant exoplanets has expanded our knowledge of other planetary systems and has demonstrated how different such systems can be from the solar system. However, their discovery poses important questions about the effects of such planets on the presence of habitable planets.

To date only one extrasolar planet—HD 209458b—has been observed to transit a parent star. This project has the potential for a 10-fold increase in the number of extrasolar planets for which transits are observed. The South Pole is an excellent location to detect such planets because randomly phased transits can most efficiently be detected during the long winter night. Also, the constant altitude of a stellar field at the pole avoids large daily atmospheric extinction variations, thus allowing for higher photometric precision and a search for smaller planets.

Specifically, we will establish an automated planet-finding photometer at the South Pole for two austral winters. The statistics of planetary systems of nearby solar-type stars would indicate that about 10 to 15 extrasolar planets should be detected. There is also the possibility of finding lower mass planets that have not previously been detectable. Combining the transit results (which give the size of the planet) with Doppler velocity measurements (which give the planetary mass) will allow the planetary density to be determined, thus indicating whether the planet is a gas giant like Jupiter, an ice giant like Uranus, or a rocky planet like the Earth. These data will provide basic observational information that is vital to theoretical models of planetary structure and formation. (A–103–S; NSF/OPP 01–26313)

Dayside auroral imaging at South Pole.

Stephen Mende and Harald Frey, University of California–Berkeley.

We plan to operate two ground-based imagers at South Pole Station and combine their observations with simultaneous global auroral observations by the IMAGE (Imager for Magnetopause to Aurora Global Exploration) spacecraft investigating temporal and spatial effects in the ionosphere from the reconnection processes at the magnetopause. The South Pole has advantages for auroral imaging because the continuous darkness during the winter allows 24 hours of optical observations and because the ideal magnetic latitude permits observation of the dayside aurora. The reconnection (merging) region of the magnetosphere provides the most significant entry point for solar wind plasma. It is now widely accepted that the dayside region contains the footprint of field lines that participate in reconnection processes with the interplanetary field.

Although there is a body of literature about the auroral footprints of the dayside reconnection region derived from ground-based observations, it has not been possible to relate those results to simultaneous global auroral images. Global observations of proton auroras from the IMAGE spacecraft have provided direct images of the footprint of the reconnection region, showing that reconnection occurs continuously and that the spatial distribution of the precipitation follows theoretically predicted behavior as a function of the interplanetary field. The apogee of the IMAGE spacecraft orbit is slowly drifting south, and during the austral winter of 2004, the apogee will be over the Southern Hemisphere. Thus, it will be possible to obtain simultaneous global images of the aurora by IMAGE and of the high-latitude dayside region by two ground-based imagers (electron and proton auroras) at South Pole Station.

Our main goal is to capitalize on this unique opportunity and use the IMAGE satellite as the telescope and the ground-based imagers as the microscope for these observations in an attempt to better understand substorms and related phenomena. Understanding the Earth's electromagnetic environment is key to predicting space weather and to determining how geoactive magnetic storms are. We will continue to involve students in every phase of the program, thereby encouraging some of them to start a career in upper-atmospheric research. (A–104–S; NSF/OPP 02–30428)

A very-low-frequency (VLF) beacon transmitter at South Pole (2001–2004).

Umran Inan, Stanford University.

This 3-year project to establish and operate a very-low-frequency (VLF) beacon transmitter at the South Pole will measure solar effects on the Earth's mesosphere and lower ionosphere. Relativistic electrons, measured at geosynchronous orbit to have energies of more than 300 kiloelectronvolts, appear to fluctuate in response to substorm and solar activity. During such events, these highly energetic electrons can penetrate as low as 30 to 40 kilometers above the Earth's surface. At that altitude, they can wreak havoc in the atmosphere: they ionize chemical species, create x rays, and may even influence the chemistry that produces ozone.

By comparing how the South Pole VLF signal varies in both amplitude and phase when it arrives at various antarctic stations, we can calculate the extent of relativistic electron precipitation. The transmitter will also produce other data on solar proton events, relativistic electron precipitation from the Earth's outer radiation belts, and the joule heating components of high-latitude/polar cap magnetosphere/ionosphere coupling processes.

VLF data from the South Pole beacon provide a valuable complement to two other efforts: first, to other antarctic upper-atmospheric research, such as the automatic geophysical observatory program and the Southern Hemisphere coherent high-frequency radar Super4 Dual Auroral Network (SUPERDARN), and second, to ongoing satellite-based measurements of trapped and precipitating high-energy electrons at both high and low altitudes. The latter are collected by the Solar Anomalous and Magnetospheric Particle Explorer (SAMPEX). (A–108–S; NSF/OPP 00–93381)

South Pole Air Shower Experiment–2.

Thomas Gaisser, Todor Stanev, and Timothy Miller, University of Delaware; and Albrecht Karle, University of Wisconsin–Madison.

Cosmic rays consist of protons and other atomic nuclei, accelerated (scientists believe) to high energy levels in such distant astrophysical sources as the remnants of supernovas. As cosmic rays arrive at Earth from space, they interact in the upper atmosphere. The South Pole Air Shower Experiment–2 (SPASE–2) is a sparsely filled array of 120 scintillation detectors spread over 15,000 square meters at the South Pole. This array detects the charged particles (primarily electrons) that are produced by interactions of these very-high-energy cosmic rays.

A nine-station subarray called VULCAN has been constructed to detect the Cherenkov radiation produced high above the ground in the same showers. (Cherenkov radiation is the light emitted by a charged particle moving through a medium at a speed faster than the speed of light within that material, analogous to the shock wave produced by objects moving faster than the speed of sound.) The SPASE–2 array is located less than half a kilometer from the top of AMANDA (the antarctic muon and neutrino detector array) and is designed to complement its neutrino-detecting capacity (see project A–130–S). SPASE–2 has two goals:

First, it is intended to investigate high-energy primary (galactic in origin) cosmic radiation by determining the relative contribution of different groups of nuclei at energies greater than about 100 teraelectronvolts. This can be done by analyzing coincident events between SPASE–2 and AMANDA. Such events are produced by high-energy cosmic ray showers with trajectories that pass through SPASE–2 (on the surface) and AMANDA (buried 1.5 to 2 kilometers beneath it). AMANDA detects the high-energy muons penetrating the Earth in those same showers for which SPASE–2 detects the low-energy electrons arriving at the surface. The ratio of muons to electrons depends on the mass of the original primary cosmic ray nucleus. The VULCAN detector further permits the calculation of two other ratios that also depend on primary mass in readings from the showers it detects.

Second, it is intended to use the coincident events as a tagged beam to investigate and calibrate certain aspects of the AMANDA response. This project is performed in cooperation with the University of Leeds in the United Kingdom. (A–109-S; NSF/OPP 99–80801)

Austral high-latitude atmospheric dynamics.

Gonzalo Hernandez, University of Washington.

Observations of atmospheric dynamics in Antarctica help us better understand the global behavior of the atmosphere in high-latitude regions. Compared with lower latitude sites, the South Pole is an interesting and unique spot from which to observe the dynamic motion of the atmosphere. Its position on the Earth's axis of rotation strongly restricts the types of wave motions that can occur.

We will use high-resolution Fabry-Perot spectrometers at South Pole Station and Arrival Heights to make simultaneous azimuthal observations of the individual line spectra of several upper-atmospheric trace species, specifically the hydroxyl radical and atomic oxygen. The observed Doppler shift of the emission lines provides a direct measure of line-of-sight wind speed; wind field structure can also be derived from these measurements. Simultaneously observed line widths provide a direct measurement of kinetic temperature.

Our goal is to observe, characterize, and understand high-latitude mesospheric motions and thermospheric persistent vertical winds near Arrival Heights simultaneously with those at South Pole Station. In both locations, observations are made during the austral winter, when the instruments operate in 24-hour data-acquisition mode. At this time, station technicians perform routine maintenance and monitor operations. During the austral summer, project team members deploy to both stations to perform maintenance and make system upgrades. (A–110–M/S; NSF/OPP 02–29251)

Riometry in Antarctica and conjugate regions.

Theodore Rosenberg, University of Maryland, and Allan Weatherwax, Siena College.

We will continue studying the polar ionosphere and magnetosphere from Antarctica and nominally conjugate regions in the Arctic. High-frequency cosmic noise absorption measurements (riometry) and auroral luminosity measurements (photometry) will form the basis of our investigations, which will involve extensive collaboration with other researchers using complementary data sets.

We will continue to maintain imaging and broadbeam riometers and two wavelength zenith photometers at South Pole and McMurdo Stations. In addition, we will continue to provide the data acquisition systems at both stations for the common recording of other geophysical data and their dissemination to collaborating investigators. To enhance the usefulness and timeliness of these data, we will maintain a homepage from which the general scientific community can access these antarctic data sets on a daily basis and, by special arrangement, in near real time. Imaging riometer measurements will also be continued at Iqaluit, Northwest Territories, Canada, which is the nominal magnetic conjugate point of South Pole Station.

Our activities will enable us to participate in, and contribute to, several major science initiatives, including the GEM, CEDAR, ISTP/GGS, and National Space Weather programs. A primary focus of our analysis will be coordinated ground- and satellite-based studies of Sun-Earth connection events. The overall objective is to understand the relevant physical processes that produce the observed phenomena and how they relate to internal and external driving forces (magnetospheric/ionospheric instabilities and solar wind/interplanetary magnetic field variations, respectively). From this may emerge an enhanced capability to predict the possible occurrence of events that might have negative technological or societal impacts sufficiently in advance to lessen their effects. (A–111–M/S; NSF/OPP 00–03881)

Polar experiment network for geophysical upper-atmospheric investigations.
Theodore Rosenberg, University of Maryland.

Continued progress in understanding the Sun's influence on the structure and dynamics of the Earth's upper atmosphere depends on increasing knowledge of the electrodynamics of the polar cap region and the key role this region plays in coupling the solar wind with the Earth's magnetosphere, ionosphere, and thermosphere. Measurements that are central to understanding include the electric field convection pattern across the polar cap and knowledge of the response of the atmosphere to the many forms of high-latitude wave and particle energy inputs during both geomagnetically quiet and disturbed situations.

The U.S. automatic geophysical observatory (AGO) network, which consists of a suite of nearly identical instruments (optical and radio wave auroral imagers, magnetometers, and narrow- and wide-band radio receivers) at locations on the polar plateau, actively studies the coupling of the solar wind to ionospheric and magnetospheric processes, emphasizing polar cap dynamics, substorm phenomena, and space weather. Among these projects are

- an investigation that uses extreme-low-frequency and very-low-frequency waves as a tool to understand the electrodynamic coupling between upper-atmospheric regions and the interaction of the magnetosphere and ionosphere;

- an investigation that employs autonomous, compact, and low-power atmospheric lidar (light detection and ranging) instruments to detect polar stratospheric clouds and profile the overlying atmosphere; and

- an investigation that uses magnetometers at conjugate sites in Antarctica and the Northern Hemisphere to measure variations in hydromagnetic waves with the optical emissions caused by charged particles that precipitate from the trapped radiation of the Earth into the upper atmosphere.

When combined with measurements made at certain staffed stations, AGO network data facilitate both large- and small-scale studies of the energetics and dynamics of the high-latitude magnetosphere. The research will be carried out with in situ observations of the geospace environment by spacecraft, in close cooperation with other nations working in Antarctica and in conjunction with studies performed in the Northern Hemisphere. (A–112–M; NSF/OPP 03–34467)

All-sky imager at South Pole.
Masaki Ejiri, National Institute of Polar Research, Japan.

The South Pole is an unparalleled platform for observing aurora during the austral winter season. As a point on the Earth's rotational axis, the pole provides a unique vantage to observe the airglow and to discern the characteristics of acoustic gravity waves in the polar region as they vary in altitude and wavelength. Observing aurora continuously over 24 hours allows us to collect data on

- the dayside polar cusp/cleft aurora (due to the direct entry of the solar wind);

- afternoon aurora that are closely associated with the nightside magnetospheric storm/substorm activities; and

- the polar cap aurora, which depends on the polarity of the interplanetary magnetic field.

Research has shown that these auroras develop from precipitating low-energy particles entering the magnetosphere from the solar wind.

Though data have been gathered at the South Pole with a film-based, all-sky camera system since 1965, newer technology now produces digital images and permits us to process large amounts of information automatically. Currently, we are using the all-sky-imager, a digital charge-coupled device imager monitored and controlled by the National Institute of Polar Research in Japan.

These international collaborations should enhance knowledge of the magnetosphere, the ionosphere, and upper/middle atmosphere physics. The high-frequency radar installations at Halley Bay, Sanae, and Syowa Stations provide the vector velocity of ionospheric plasma over the South Pole. These studies should provide further insight into the physics of the magnetosphere, the convection of plasma in the polar cap, and solar wind effects, specifically dayside auroral structure, nightside substorm effects, and polar cap arcs. (A–117–S; U.S./Japan agreement)

Spaceship Earth: Probing the solar wind with cosmic rays.

John Bieber, William H. Matthaeus, and K. Roger Pyle, Bartol Research Institute, University of Delaware, and Evelyn Patterson, U.S. Air Force Academy.

Cosmic rays—penetrating atomic nuclei and electrons from outer space that move at nearly the speed of light—continuously bombard the Earth. Colliding with the nuclei of molecules found in the upper atmosphere, they create a cascade of secondary particles that shower down on Earth. Neutron monitors, which are deployed in Antarctica and are part of a global network of nine stationary monitors and two transportable ship-borne monitors, provide a vital three-dimensional perspective on this shower and how it varies along all three axes. Accumulated neutron-monitor records (begun in 1960 at McMurdo Station and in 1964 at Amundsen-Scott South Pole Station) provide a long-term historical record that supports efforts to understand the nature and causes of solar/terrestrial and cosmic ray variations as they are discerned over the 11-year sunspot cycle, the 22-year Hale cycle, and even longer time scales. Data from the neutron monitors in this network will be combined with data from other ground-based and spacecraft instruments in various investigations of cosmic rays in relation to the Sun and solar wind. Specific objectives include the study of acceleration and transport of solar energetic particles, the scattering of cosmic rays in the solar wind, and the use of cosmic-ray observations for space weather forecasting.

This project continues a series of year-round observations at McMurdo and Amundsen-Scott South Pole Stations recording cosmic rays with energies in excess of 1 billion electronvolts. These data will advance our understanding of a number of fundamental plasma processes occurring on the Sun and in interplanetary space. At the other extreme, we will study high time-resolution (10-second) cosmic ray data to determine the three-dimensional structure of turbulence in space and to elucidate the mechanism by which energetic charged particles scatter in this turbulence. (A–120-M/S; NSF/OPP 00-00315)

Tracer-Lite II Project: Transition Radiation Array for Cosmic Energetic Radiation.

Dietrich Müller, University of Chicago.

The origin of high-energy cosmic rays remains a mystery. To solve this mystery, it is important to determine the energy spectrum of cosmic rays at the source, which is known to be different from the observed energy spectrum, at least over a narrow range of energies. Examining the chemical composition of cosmic rays at high energies provides the only means of determining the cosmic ray spectrum at the source. The steeply falling energy spectrum of cosmic rays requires long observation times with large detectors. The Transition Radiation Array for Cosmic Energetic Radiation (TRACER) was constructed for long-duration balloon flights around the polar circle. It will study the abundance of elements from oxygen to iron in the cosmic ray spectrum up to approximately 10 tera electron volts/nucleon. Such information can be used to constrain models of cosmic ray propagation and acceleration.

The instrument requires careful handling and storage. During its trip from Port Hueneme to Williams Field, its temperature must remain between 0°C and +40°C. Project members will arrive in Antarctica at intervals as the mission unfolds: one will arrive early to help unload, transport, and store the instrument. Then, others will arrive to unpack it and prepare it for flight. Once that stage is complete, different personnel will be responsible for monitoring the flight. After the flight, still other personnel will take part in the recovery phase, dismantle the instrument, and pack it for return shipment to Port Hueneme. (A–125–M; NASA award)

A versatile electromagnetic waveform receiver for South Pole Station.

James LaBelle, Dartmouth College, and Allan Weatherwax, Siena College.

The Earth's aurora naturally emits a variety of low-frequency (LF), medium-frequency (MF), and high-frequency (HF) radio waves that are signatures of the interaction between the auroral electron beam and the ionospheric plasma. Yet some of the mechanisms that generate plasma waves are not well understood. This project focuses on several types of signals detectable at ground level, including auroral hiss, which occurs primarily at very low frequencies but often extends into the LF/MF range, and auroral roar, a relatively narrowband emission generated near or at the second and third harmonics of the electron cyclotron frequency.

We will use a versatile electromagnetic waveform receiver deployed at South Pole Station. Only recently has it been possible to conceive of an inexpensive, versatile receiver of this type for the South Pole. An antarctic location is essential for ground-based observations of LF auroral hiss because the broadcast bands usually found in the Northern Hemisphere are typically absent in Antarctica. Also, the absence of broadcast bands improves the effectiveness of automatic wave-detection algorithms.

We can use the receiver to address many issues. For example, it was recently discovered that auroral roar is sometimes modulated at frequencies between 7 and 11 hertz, a phenomenon called flickering auroral roar. This receiver will allow us to find out how common flickering auroral roar is, the conditions under which it occurs, what the frequencies are, and how the amplitude and frequency vary over time.

Between 15 percent and 30 percent of auroral hiss events are not observable at very low frequencies. The receiver will determine whether LF auroral hiss consists exclusively of relatively unstructured broadband impulses or whether it sometimes displays a fine structure similar to that of auroral kilometric radiation and whistler-mode waves in the same frequency range detected in the lower ionosphere. We will also define and test auroral roar and auroral hiss mechanisms. Despite its extensive application for communications, the

LF/MF/HF band has been relatively little investigated as a source of natural radio emissions detectable at ground level.

A complete knowledge of our geophysical environment requires understanding the physics of these emissions. Further, electron beam–plasma interactions analogous to terrestrial aurora occur in many space physics and astrophysics applications. Often, the electromagnetic radiation emitted by these systems is our only source of knowledge about them. The local auroral plasma provides an opportunity to view some plasma radiation processes at close range. (A–128–S; NSF/OPP 00–90545)

Effects of enhanced solar disturbances during the 2000–2002 solar-max period on the antarctic mesosphere-lower-thermosphere (MLT) and F regions composition, thermodynamics, and dynamics.

Gulamabas Sivjee, Embry Riddle Aeronautical University.

While variations in the Sun's energy affect people in obvious ways by driving the weather and the seasons, there are actually many cycles and variations of deeper interest to science, on scales from seconds to centuries to eons. One of the most basic is the 11-year cycle when the Sun's magnetic poles reverse direction (since reliable observations began, 23 of these have occurred and the last just recently peaked), and sunspots and other solar activity wax to peak levels. The National Aeronautics and Space Administration is using this opportunity to conduct its TIMED (thermosphere-ionosphere-mesosphere-energetics and dynamics) satellite study, which will focus on the region between 60 and 180 kilometers above the Earth's surface.

Taking advantage of the timing of both of these events, we will use observations in the visible and near-infrared ranges of upper-atmospheric emissions above South Pole Station to study the heating effects of auroral electrical currents in the ionosphere, as well as planetary waves and atmospheric tides.

As it passes overhead, TIMED will provide data on the temperature, winds, and tides of the Earth's upper atmosphere, especially above the poles. But tracking satellites often have difficulty differentiating between variations in location or time. South Pole ground-based observations will be valuable in sorting out the time-location question. (A–129–S; NSF/OPP 99–09339)

Antarctic muon and neutrino detector array (AMANDA).

Robert Morse, Frances Halzen, and Albrecht Karle, University of Wisconsin–Madison.

The AMANDA project takes advantage of unique polar conditions to discover and probe the sources, both inside our galaxy and beyond, of the shower of very-high-energy neutrinos descending on (and usually passing through) the Earth. Neutrinos are elementary particles believed to have very little or no mass and no electrical charge. Coursing through the Universe, they can take any of three forms and interact only rarely with other particles. Thus they arrive on Earth with potentially unique information about where they may have originated. They could be diffuse (made up of contributions from many active galactic nuclei) and may even be an indicator of the decomposition of the mysterious dark matter now believed to dominate the Universe. Or they could be single sources, such as supernova remnants, rapidly rotating pulsars, the gas around black holes, neutron stars, or individual blazars.

AMANDA is the largest detector of neutrinos in the world. During the past 5 seasons, the installation of over 600 photomultiplier tubes [embedded between 1 and 2 kilometers (km) into the ice and oriented downward] has established a natural detector of Cherenkov radiation in the ice. (Cherenkov radiation is the light emitted by a charged particle moving through a medium at a speed faster than the speed of light within that material, analogous to the shock wave produced by objects moving faster than the speed of sound.) High-energy neutrinos with enough energy to pass through the Earth's mass may collide with an atomic nucleus in the ice or rock near the tubes. Such collisions produce a distinctive eerie blue glow, which the basketball-sized glass tubes can detect for up to several hundred meters through the clear ice.

Neutrino astronomy has previously been limited to the detection of solar neutrinos, plus one brief, spectacular burst from the supernova that appeared in the Large Magellanic Cloud in February 1987 (SN–1987a). In recent years, new sources of high-energy gamma rays have been discovered, among them Mrk–421, which was seen by the National Aeronautics and Space Administration's Compton Gamma Ray Observatory and the Mount Hopkins Observatory. AMANDA is designed to study just such objects, which are believed to emit copious numbers of high-energy neutrinos. Now that first-generation detectors such as AMANDA have been enhanced (the array may one day number 5,000 tubes strung on some 80 cables within 1 cubic km of ice), neutrino astronomy would appear to be on the verge of detecting high-energy particles that carry information from the outer edges of the universe. (A–130–S; NSF/OPP 99–80474)

Measurements addressing quantitative ozone loss, polar stratospheric cloud nucleation, and large polar stratospheric particles during austral winter and spring.

Terry Deshler, University of Wyoming and Alberto Adriani, Instituto di Fisica dell'Atmosfera, Rome, Italy.

The stratospheric ozone layer provides life on Earth with an essential shield from solar ultraviolet radiation. The discovery in 1985 of large ozone losses above Antarctica each spring took the world and the scientific community by surprise. Since that time, the cause of this unprecedented ozone loss has been determined to be chlorine compounds interacting on the surfaces of clouds that formed the previous winter [polar stratospheric clouds (PSCs)]. This interaction helps explain why ozone depletion is so severe in the polar regions. However, many details must still be clarified before we can comprehensively model the stratospheric ozone balance. An international experiment to address some of these details is planned for June through October 2003.

This experiment will compare balloon-borne ozone observations from nine antarctic stations (South Pole, General Belgrano II, Dumont d'Urville, Vicecomodoro Marambio, Georg von Neumayer, Rothera, Syowa, Davis, and McMurdo) with several three-dimensional chemical transport models. Balloon releases will be coordinated to sample air parcels previously sampled at another location. Comparing the changes within these air parcels will provide an excellent test of our understanding of stratospheric chemistry as represented in the models.

Observations from McMurdo Station will also add to our database of annual vertical ozone profiles and will be completed as stratospheric chlorine levels are peaking to provide a baseline to detect the first signs of ozone recovery. In addition to these ozone observations, we will extend our observations of PSCs. We use an optical radar (lidar, light detection and ranging) to study PSCs, stratospheric aerosol, and the thermal behavior and dynamics of the atmosphere above McMurdo Station. Continuous lidar observations provide insight into these PSCs, more specifically, estimates of the size and concentration of the particles that form in them and estimates of the surfaces available for heterogeneous chemistry (the activation of chlorine so it can destroy ozone), of the rates of denitrification and dehydration, and of particle composition.

Measurements of vertical ozone profiles are archived in the database of the Network for the Detection of Stratospheric Change, a global set of high-quality remote-sounding research stations for observing and understanding the physical and chemical state of the atmosphere (see http://www.ndsc.ws). This project represents a collaboration between Italian researchers and the University of Wyoming. (A–107–M and A–131–M; NSF/OPP 02–30424 and U.S./Italian agreement)

Measurement and analysis of extremely-low-frequency (ELF) waves at South Pole Station.

Marc R. Lessard and James LaBelle, Dartmouth College.

We aim to detect and record magnetic field fluctuations in the extremely-low-frequency (ELF) range at South Pole Station, specifically auroral ion cyclotron waves, which have been well correlated with flickering aurora. Theory predicts that these waves modulate precipitating electron fluxes, thereby causing the flickering in luminosity emissions. Substantial evidence now supports this theory, although the excitation mechanism responsible for the ion cyclotron waves is somewhat uncertain. Perhaps the most well developed theory suggests that the waves result from an electron-beam instability. In any case, the frequency of the flickering or, equivalently, the frequency of the ground-based observations of ion cyclotron waves can be used to infer the altitude of the excitation mechanism, since the wave frequency depends on the strength of the background magnetic field, which is a known quantity. As such, the information that will be acquired can be used to test models of auroral acceleration mechanisms, as well as study dispersive ELF waves, a type of wave that has been reported in the literature only a few times, but one that may provide important information on substorm onset or, perhaps, the boundaries of open and closed magnetic fields.

A first step is to identify the wave mode and to determine the location and geomagnetic conditions under which these waves can be observed. The equipment used to make these observations consists of an induction coil magnetometer and data acquisition system. The induction coil is a commercially available device, one that was originally designed for geophysical exploration. Data will be returned to Dartmouth College for analysis. (A–136–S; NSF/OPP 01–32576)

Development and test flight of a small, automated balloon payload for observations of terrestrial x-rays.

David Smith, University of California–Berkeley.

We plan to develop and test a balloon payload designed to detect mega electron volt (MeV) electron precipitation into the atmosphere from the Earth's radiation belts. Relativistic electron precipitation has been found to occur at high latitudes, but it is not known how common such events are, nor is much known about the conditions that lead to these events. These particles endanger astronauts and unmanned satellites, but neither the cause of their energization nor the cause of their loss (precipitation) is well understood. The precipitation of the highest energy electrons occurs in rare, rapid events that we will study with a balloon payload.

The instrument we will develop will be very small and lightweight, and it will include real-time data communications via the Iridium satellite system. This new technology will allow a payload that can be launched on small balloons as well as on long-duration balloons. (A–144–M; NSF/ATM 02–33370)

Long-duration balloon program.

William Stepp, National Aeronautics and Space Administration/National Scientific Balloon Facility.

As a means of high-altitude exploration, free-flying balloons have many advantages over satellites. Balloons remain in a specific location much longer, cost little to launch, and are designed to return their instruments safely to Earth. Balloons have been flying for two centuries, but until recently were limited by how long they could stay aloft. The latest scientific balloons, deployed from the National Scientific Balloon Facility (NSBF) in Palestine, Texas, are able to fly missions of 100 days or longer.

The current NSBF effort in Antarctica, known as the long-duration balloon (or LDB) program, launches high-altitude balloons carrying scientific payloads into the stratosphere. Many important scientific observations in fields such as hard x-ray/gamma ray and infrared astronomy, cosmic rays, and atmospheric studies have been made from balloons. (A–145-M; NSF/NASA agreement)

Trans-Iron Galactic Element Recorder/ANITA-lite (TIGER–ANITA-lite).
Walter Binns, Washington University.

Our primary objectives for the Trans-Iron Galactic Element Recorder (TIGER) experiment are to measure ultra-heavy galactic cosmic rays in order to determine the source of the material that is accelerated as galactic cosmic rays and the mechanism for injecting that material into the cosmic ray accelerator. Specifically, TIGER will build on our previous work and will collect additional data in order to measure the abundance of the elements in the charge range of interest. Our primary objectives for the Antarctic Impulsive Transient Antenna (ANITA)–lite experiment, which will fly on the same balloon with TIGER, are to measure the ambient very-high-frequency and ultra-high-frequency (VHF/UHF) impulsive noise levels at float altitudes over the antarctic ice sheet. The ANITA-lite experiment is a pathfinding mission for the ANITA experiment, which is a neutrino telescope that will be designed to detect neutrinos converting in the polar ice sheet.

We will place these experiments on an long-duration balloon that will fly two revolutions around Antarctica to obtain a long data acquisition time for galactic cosmic rays (TIGER) and VHF/UHF impulsive noise levels (ANITA-lite). We will collaborate with the National Scientific Balloon Facility (NSBF), which will ship our experiment and associated equipment to McMurdo Station, provide laboratory space for integration and testing, launch the TIGER/ANITA-lite payload from Williams Field, and conduct flight operations. We will monitor the experiment with electronic ground support equipment at Williams Field for line-of-sight data. Following the flight, NSBF and project personnel will recover the instrument and ship it back to the United States. (A–149–M; NASA award)

Infrared measurements of atmospheric composition over Antarctica.
Frank Murcray, Ronald Blatherwick, and Pierre Fogal, University of Denver.

Using passive infrared instruments, we will measure year-round atmospheric chemistry to acquire better data for the photochemical transport models used to predict ozone depletion and climate change. The ozone hole has shown how sensitive the southern polar stratosphere is to chlorine, and although gradual healing of the hole is expected, model predictions indicate a possible delay in recovery because of the impact of global warming on the catalytic ozone destruction process.

Since most satellite instruments do not sample the polar regions in the winter, ground-based instruments can make important contributions, and the data from our instruments would also provide validation for new satellite sensors. We will install two spectrometers, one at South Pole Station and another at McMurdo Station for year-round operation, and a solar spectrometer at South Pole Station for summer operation. Also, we will collaborate with and receive data from the New Zealand National Institute for Water and Air Research, which operates a similar solar spectrometer at Arrival Heights. During the polar night, two instruments will provide important information on nitric acid and denitrification, as well as dehydration, and high-resolution spectra from which we will derive vertical profiles, vertical column amounts of many molecules important in the ozone destruction process, and atmospheric tracers. Specifically, we will derive year-round column abundance measurements of nitric acid, methane, ozone, water, nitrous oxide, the chlorofluorocarbons (CFCs), and nitrogen dioxide.

The solar instruments will provide some altitude profile information about those molecules and others. The data set we obtain will be used to determine the current state of nitrogen oxide partitioning; to measure denitrification, vapor profiles in the stratosphere, and dehydration; to determine current CFC and stratospheric chlorine levels; and to gain more insight into vortex-related chemical and dynamic effects.

In addition, the data will allow photochemical transport modelers to compare outputs with actual measurements, especially at intermediate stages. As the recovery from ozone destruction begins, it is important to have a data set that comprehensively covers the major constituents of both the catalytic ozone destruction sequence and global warming, in order to place the relative influence of the two mechanisms in perspective. (A–255–M/S; NSF/OPP 02–30370)

Dynamics of the antarctic mesosphere-lower-thermosphere region using ground-based radar and TIMED instrumentation.
Susan K. Avery, James Avery, and Scott Paolo, University of Colorado–Boulder, and Denise Thorsen, University of Alaska.

This is a propitious time to study a number of atmospheric phenomena, because the 11-year solar cycle has peaked and because of the National Aeronautics and Space Administration's (NASA's) TIMED (thermosphere-ionosphere-mesosphere-energetics and dynamics) satellite mission (see project A–129–S). In addition to measurements derived from TIMED instruments, we have installed a meteor radar at

Amundsen-Scott South Pole Station. Concentrating on the dynamics of the mesosphere and lower thermosphere, we are looking at

- the space-time decomposition of wave motions,
- the delineation of the spatial climatology over Antarctica with emphasis on the structure of the polar vortex, and
- the dynamic response to energetic events and interannual variability.

The meteor radar is a very-high-frequency system capable of measuring the spatial structure and temporal evolution of the horizontal wind field over the South Pole. Spatial climatology data will also come from existing ground-based radar at Davis Station, Syowa Station, Rothera Station, and the Amundsen-Scott base.

As NASA's TIMED satellite orbits over the South Pole, wind and temperature data will provide counterpoint and corroborative information. Thus, experiments based both in space and on the ground can be mounted, and data that previously relied on a single source can be better validated. (A–284–S; NSF/ATM 00–00957)

Global thunderstorm activity and its effects on the radiation belts and the lower ionosphere.

Umran Inan, Stanford University.

Tracking dynamic storms is a challenge, but lightning associated with thunderstorms can provide scientists with an indirect way of monitoring global weather. This project employs very-low-frequency (VLF) radio receivers located at Palmer Station; they are operated in collaboration with the British and Brazilian Antarctic Programs, both of which have similar receivers. All are contributors to the Global Change Initiative.

The VLF receivers measure changes in the amplitude and phase of signals received from several distant VLF transmitters. These changes follow lightning strokes because radio (whistler) waves from the lightning can cause very energetic electrons from the Van Allen radiation belts to precipitate into the upper atmosphere. This particle precipitation then increases ionization in the ionosphere, through which the propagating VLF radio waves must travel. Because the orientations to the VLF transmitters are known, it is possible to triangulate the lightning sources that caused the changes. Once the direction of the lightning source is known, it can be subjected to waveform analysis and used to track—remotely—the path of the thunderstorms.

The data will also be correlated with data from the antarctic automatic geophysical observatory network and will be used by scientists studying the magnetosphere and the ionosphere. (A–306–P; NSF/OPP 02–33955)

IceCube.

Francis Halzen, University of Wisconsin–Madison.

We will begin building the IceCube Observatory, which will be installed at the South Pole. IceCube, a neutrino telescope that will be buried 1.4 to 2.4 kilometers below the surface of the ice, will be constructed during the austral summers over the next 6 years. The detector will consist of 4,800 optical modules deployed on 80 vertical strings. AMANDA (see the Antarctic Muon and Neutrino Detector Array project, A–130–S) serves as a prototype for this international collaborative effort.

Using neutrinos as cosmic messengers, IceCube will open an unexplored window on the Universe and will answer such fundamental questions as what the physical conditions in gamma ray bursts are and whether the photons originating in the Crab supernova remnant and near the super massive black holes of active galaxies are of hadronic (derived from subatomic particles composed of quarks) or electromagnetic origin. The telescope will also examine the nature of dark matter, aid in the quest to observe super symmetric particles, and search for compactified dimensions.

This season we will plan the schedule and begin assembling and testing the components and drilling systems we will use to construct the observatory. Since many parts of the Universe cannot be explored using other types of radiation (protons do not carry directional information because they are deflected by magnetic fields, neutrons decay before they reach the Earth, and high-energy photons may be absorbed), IceCube will fill a gap in our knowledge and occupy a unique place in astronomical research. (A–333–S; NSF/OPP 02–36449)

Antarctic Submillimeter Telescope and Remote Observatory (AST/RO).

Antony Stark, Smithsonian Institution Astrophysical Observatory.

Astronomy is undergoing a revolutionary transformation, where for the first time we can observe the full range of electromagnetic radiation emitted by astronomical sources. One of the newly developed and least explored bands is the submillimeter, at frequencies from about 300 gigahertz up into the terahertz range. Submillimeter-wave radiation is emitted by dense gas and dust between the stars, and submillimeter-wave observations allow us to study the galactic forces acting on that gas and the star formation processes within it in unprecedented detail.

The Antarctic Submillimeter Telescope and Remote Observatory (AST/RO) is a 1.7-meter, single-dish instrument that has been operating for 9 years in several submillimeter bands. It has made position-position-velocity maps of submillimeter-wave spectral lines with arcminute resolution over regions of sky that are several square degrees in size. AST/RO provides a valuable complement to the planned arrays, which are inefficient when observing large areas because of their small field of view. AST/RO can observe molecular clouds throughout the fourth quadrant of the Milky Way and the Magellanic Clouds to locate star-forming cores and study in detail the dynamics of dense gas in our own galaxy. AST/RO studies are showing how molecular clouds are structured, how the newly formed stars react back on the cloud, and how galactic forces affect cloud structure. Also, these studies have

- shown that the structure of molecular clouds is affected by their heavy element content and their proximity to spiral arms,
- examined the gradient of heavy elements in the galaxy, and
- recently produced extensive, high-sensitivity maps of several atomic and molecular transitions toward the Galactic Center.

Essential to AST/RO's capabilities is its location at Amundsen-Scott South Pole Station. Most submillimeter radiation is absorbed by irregular concentrations of atmospheric water vapor before it reaches the Earth's surface. The desiccated air over South Pole Station allows an accurate intercomparison of submillimeter-wave power levels from locations on the sky separated by several degrees. This is essential to the study of submillimeter-wave radiation on the scale of the Milky Way and its companion galaxies.

We will devote equal effort to three initiatives: large-scale maps of emissions in the Galactic Center and the Magellanic Clouds (these will be made freely available), support of proposals from the scientific community, and installation and use of the detector systems under development. (A–371–S; NSF/OPP 01–26090)

DASI (degree angular scale interferometer).

John Carlstrom, University of Chicago.

We plan to continue cosmological observations with DASI (degree angular scale interferometer), which was first deployed at the Amundsen-Scott South Pole Station during the 1999–2000 austral summer. DASI is providing continuous high-quality measurements of the cosmic microwave background (CMB) radiation anisotropy over the critical range of angular scales spanning the first three acoustic peaks in the CMB power spectrum. The data are transferred daily to the University of Chicago, where analysis is keeping pace with the data. We published the resulting power spectrum in *Nature* in December 2002 and intend to publish again in 2003.

We will also use DASI to measure the currently undetected polarization of the CMB anisotropy. The measurements will provide a critical test of the standard theory of the early Universe. The observations will also be done using full Stokes parameters, allowing a measurement of the cross-correlation of total intensity and polarization anisotropy. We will construct new receiver components to reconfigure DASI from 30 gigahertz (GHz) to 100 GHz for intensity and polarization measurements of the fine-scale CMB anisotropy power spectrum. These new capabilities will allow detailed observations of the Sunyaev-Zel'dovich Effect (SZE) in nearby galaxy clusters and allow SZE surveys from massive clusters.

These efforts complement other ongoing and planned CMB experiments with instruments in Chile and at the South Pole. These three instruments can view the same region of the sky and will provide detailed power spectra over this angular range, thereby gathering crucial data for understanding foreground contamination. These three instruments, working together, will allow this essentially unexplored but theoretically important portion of the CMB anisotropy power spectrum to be fully determined.

We will disseminate and implement outreach and education related to the project through established structures and mechanisms. These programs, which reach out to local and distant K–12 schoolteachers and students, will use the excitement of exploring our Universe to help attract women and minorities to science. Also, we will integrate graduate and undergraduate education and research into the construction of the instrumentation, as well as into the data analysis. (A–373–S; NSF/OPP 00–94541)

Mapping galactic magnetic fields with the submillimeter polarimeter for antarctic remote observations (SPARO).

Giles Novak, Northwestern University.

The submillimeter polarimeter for antarctic observations (SPARO) maps interstellar magnetic fields by measuring the linear polarization of submillimeter thermal emission from magnetically aligned interstellar dust grains. Interstellar magnetic fields are generally difficult to observe, especially in the dense regions to which SPARO is most sensitive. It is important to study these fields because their energy density is comparable to that of the other physical ingredients that are found in interstellar regions, so they can play important roles in the physical processes that occur there. This program is designed to contribute to our understanding of two general problems in which interstellar gas (and probably magnetic fields as well) has an important role: the study of the Galactic Center region and star formation.

The study of the super-massive black holes that are found at the centers of many galaxies is motivated in part by our desire to understand the behavior of nature in such extreme environments and in part by the likely influence of these active galactic nuclei on the evolution of galaxies and perhaps of the Universe. Also, magnetic fields in star-forming regions may help support star-forming clouds against gravity, or they may help clouds collapse via angular momentum transfer. The SPARO instrument is operated on the Viper 2-meter telescope at the South Pole. Observations are carried out by personnel who remain there for the 8-month winter when South Pole Station is inaccessible. These observations are complementary to submillimeter polarimetry that is being carried out by larger telescopes at Mauna Kea, but SPARO is much more sensitive to submillimeter emissions because of the exceptionally good atmospheric transmission and the stability of the winter skies over the antarctic plateau.

Therefore, our observations are specifically aimed at

- confirming SPARO's discovery of a large-scale toroidal magnetic field at the Galactic Center;
- testing a magnetic outflow model for the Galactic Center Lobe, a radio structure possibly tracing gas that has been ejected from the galactic nucleus; and
- mapping large-scale magnetic fields in a sample of star-forming clouds to study the relationship between the elongated shapes of these clouds and their magnetic fields. (A–376–S; NSF/OPP 01–30389)

Wide-field imaging spectroscopy in the submillimeter: Deploying SPIFI on the Antarctic Submillimeter Telescope and Remote Observatory (AST/RO).
Gordon Stacey, Cornell University.

SPIFI (the South Pole Imaging Fabry-Perot Interferometer) is the first direct detection imaging spectrometer for use in the submillimeter band and was designed for use on the 1.7-meter Antarctic Submillimeter Telescope and Remote Observatory (AST/RO) at the South Pole in the far-infrared and submillimeter windows. After having developed and extensively field-tested SPIFI, our primary scientific goals are to

- image the inner regions of the galaxy, in particular submillimeter lines that characterize excitation conditions in the Central Molecular Zone (CMZ), and trace the dynamics of the gas. Questions to be answered are, among others, Can we trace neutral gas flowing through the CMZ? Are there shocks from cloud-cloud collisions in this flow? What is the connection between the CMZ molecular clouds and the circumnuclear ring?
- map the Large Magellanic Cloud and Small Magellanic Cloud in these lines. The low metalicity environment in these dwarf galaxies may mimic that of protogalaxies, so that investigating the interaction between star formation and the interstellar matter in these galaxies is key to understanding the star formation process in the early Universe.
- characterize and map the physical conditions of the interstellar matter in nearby galaxies. These data are unique and will be essential to understanding the relationships between density waves, bar potentials, and galaxy-wide star formation.

These projects can be undertaken only with the high sensitivity and mapping capabilities of the SPIFI AST/RO combination. SPIFI is much more sensitive than the best heterodyne receivers, which do not have the sensitivity, or (often) the bandwidth, to detect the broad, weak lines from galaxies or the spatial multiplexing capability necessary for wide-field mapping projects. We plan to gradually upgrade SPIFI by a factor of 10. We will also make modest optical and cryogenic modifications to improve SPIFI in ways important to successful polar operations. The result will be better spatial resolution, with a wider field of view, and a large improvement in system sensitivity. Moreover, the new cryogenic system will require servicing only every 5 days instead of the current 40 hours. This is helpful for outdoor polar operations. This new system also reduces helium consumption (by a factor of 2) and therefore reduces cost. (A–377-S; NSF/OPP 00–94605)

High-resolution observations of the cosmic microwave background (CMB) with the Arcminute Cosmology Bolometer Array Receiver (ACBAR).
William Holzapfel, University of California–Berkeley.

We will continue our observations with the Arcminute Cosmology Bolometer Array Receiver (ACBAR), a 16-element 230-micro-Kelvin bolometer receiver designed to produce high-resolution images of the cosmic microwave background (CMB) in 3-mm wavelength bands. Mounted on the 2.1-meter Viper telescope at the South Pole, ACBAR has sensitivity that rivals balloon-borne experiments and angular resolution that they cannot hope to achieve. Making full use of the excellent atmospheric conditions in the austral winter at the South Pole, ACBAR is producing images of CMB radiation with sensitivity and resolution that exceed the capabilities of even the European Space Agency's proposed Planck satellite (to be launched in 2007)

Observations of the CMB provide a unique window on the early Universe; moreover, these data play a key role in transforming cosmology into a precise science. In particular, small angular-scale observations of the CMB are a new frontier about which comparatively little is known. On these angular scales, contributions from secondary anisotropies introduced by intervening structures are expected to become dominant. For example, the scattering of photons by hot gas bound to clusters of galaxies results in a spectral distortion of the CMB known as the Sunyeav-Zel'dovich Effect (SZE). Observations of the SZE can provide important new constraints on theories of how the Universe grew.

The unique capabilities of ACBAR, which was deployed to the South Pole in December 2000, allow it to address a broad range of science focused on measuring primary and secondary CMB anisotropies. Our observations and analysis will help realize the full potential of this powerful instrument for the study of cosmology. Four institutions will continue to collaborate in the maintenance and operation of ACBAR and Viper and participate in the data analysis.

The results will serve as a vital complement to the large-scale Microwave Anistropy Probe (MAP) spacecraft data set and provide an essential check of the fine-scale excess power reported by other single-frequency experiments. The novel instrumentation, observation techniques, and analysis developed for ACBAR are generally applicable to future ground-based millimeter astronomy experiments. In addition, this project has provided hands-on research experience to several undergraduate and graduate students. (A–378–S; NSF/OPP 02–32009)

South Pole observations to test cosmological models: A 10-meter telescope for South Pole.

John Carlstrom, University of Chicago; Antony Stark, Smithsonian Institution Astrophysical Observatory; John Ruhl, Case Western Reserve University; Joseph Mohr, University of Illinois–Urbana-Champaign; and William Holzapfel, University of California–Berkeley.

One of the most important discoveries in cosmology is that apparently much, if not most, of the mass in the Universe is made up not of stars and glowing gas, but of dark matter, which emits little or no light or other electromagnetic radiation and makes its presence known only through the gravitational force it exerts on luminous matter. There is some indication that dark matter may in fact not even be baryonic (baryons are subatomic particles that are built from quarks and interact via strong nuclear force). Just what fraction of the mass is in the form of noninteracting nonbaryonic particles is of great interest to cosmologists and physicists.

The University of Chicago will lead a consortium of six institutions to design and use a 10-meter off-axis telescope at Amundsen-Scott South Pole Station to survey galaxy clusters. This survey will allow us to study integrated cluster abundance and its red shift evolution and will give us precise cosmological constraints that are completely independent of those from supernova distance and cosmic microwave background (CMB) anisotropy measurements.

Measuring the mass in baryons along with the total mass in a region of the Universe that could be considered a fair sample would provide a crucial direct determination of the dark matter content. In recent years, just such a test-bed has been found in massive clusters of galaxies, which contain large amounts of gas (baryons) in the form of a highly ionized gas atmosphere that emits x rays. Nearly all of the baryons in the clusters are believed to be in the hot phase (millions of degrees), and so it is likely that we are truly measuring the baryonic mass in the cluster.

In addition to emitting x rays, the hot cluster gas also scatters CMB radiation. This scattering, called the Sunyaev-Zel'dovich Effect (SZE), is measurable using radio telescopes. The SZE is important to the study of cosmology and the CMB for two main reasons:

The observed hotspots created by the kinetic effect will distort the power spectrum of CMB anisotropies. These need to be separated from primary anisotropies in order to probe inflation properties.

The thermal SZE can be measured and combined with x-ray observations to determine the values of cosmological parameters, in particular the Hubble constant. (A–379–S; NSF/OPP 01–30612)